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Review

Risks of Climate Change with Respect to the Singapore-Malaysia High Speed Rail System

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Abstract: Warming of the climate system is unequivocal, and many of the observed changes are unprecedented over the past five decades. Globally, the atmosphere and the ocean are becoming increasingly warmer, the amount of ice on the earth is decreasing over the oceans, and the sea level has risen. According to the Intergovernmental Panel on Climate Change, the average increase in global temperature (combined land and surface) between the 1850–1900 period and the 2003–2012 period was 0.78 °C (0.72 to 0.85). But should we prepare for such a relatively small change? The importance is not the means of the warming but the considerable likelihood of climate change that could trigger extreme natural hazards. The impact and the risk of climate change associated with railway infrastructure have not been fully addressed in the literature due to the differences in local environmental parameters. On the other hand, the current railway network in Malaysia, over the last decade, has been significantly affected by severe weather conditions such as rainfall, lightning, wind and very high temperatures. Our research findings based on a critical literature review and expert interviews point out the extremes that can lead to asset system failure, degraded operation and ultimately, delays in train services. During flooding, the embankment of the track can be swept away and bridge can be demolished, while during drought, the embankment of the track can suffer from soil desiccation and embankment deterioration; high temperature increases the risk of track buckling and high winds can result in vegetation or foreign object incursion onto the infrastructure as well as exert an additional quasi-static burden. This review is of significant importance for planning and design of the newly proposed high speed rail link between Malaysia and Singapore.

Keywords: railway infrastructure; high-speed rail; tracks; risk; management and monitoring; climate change; global warming; adaptation; operational readiness; project development planning

1. Introduction

In recent years, there has been increasing interest to the policy makers to build High Speed Rails (HSRs) worldwide, including Malaysia. To develop this new form of transportation, the Malaysian government needs to ascertain that its new HSR system can cope with and adapt to climate change. In addition, the complexities of climate change and predictions of climate model outputs have introduced an additional measure of uncertainty for railroad operators [1,2]. Extreme weather has affected railway operations and safety, including fatalities, injuries and property damage. Despite climate change posing serious challenges to infrastructure projects, little research has been conducted in Malaysia into how vulnerable it could be, especially for transport infrastructure. It has been widely recognized that there is a need to integrate the consideration of climate change and its impacts into the development of policies and projects [3]. "Decisions made today—for example, in the creation of new infrastructure or other assets—need to occur in a way which ensures that the outcomes of those decisions are robust enough to cope with, or adapt to, changing climatic conditions in the future" [4]. Although climate change adaptation measures have been proposed to respond to extreme events at a higher level by many researchers [5–10], the infrastructure vulnerabilities and resilience-based design have not been addressed since their real impacts are truly associated with local parameters such as topology, geography, design and maintenance practice, and so on. For example, a reduced train speed will apply when the ambient temperature reaches a certain degree, but more effective rail stress management (such as rail creep adjustment, rail joints, stress-free fasteners, etc.) has not been discussed [10]. This has raised a research question and investigation to better understand the fundamental risks and impact of climate change and corresponding infrastructure vulnerabilities to pertinent extreme conditions. The present risk concept does not provide any specific asset management strategy to meaningfully repair, retrofit or replace any component effectively in a particular region, such as Malaysia [11]. As such, this paper serves to provide pathway for detailed and tailored adaptation solutions and to appropriately plan the resilience-based design and the development of the HSR system.

High Speed Rail (HSR) from Kuala Lumpur, Malaysia to Singapore, which is still in its planning stage (at the time of writing), would be the first of its kind in Malaysia. Prime Ministers of Malaysia and Singapore jointly announced the HSR project on the 19 February 2013 and described the HSR as a "Game Changer". The project target is to be fully operational by 2020. The key concept of the HSR was derived by the Malaysia Land Public Transport Commission (SPAD) and it will have 7 stations, 2 terminal stations, which are in Kuala Lumpur and Singapore, 5 transit stations, one in Negeri Sembilan and Malacca, and 3 in Johor. The HSR will have 2 operation systems, which are express, non-stop journey from Kuala Lumpur to Singapore, and the estimated journey time is 90 min, while the HSR Malaysia transit operation will have 7 stops including a terminus station, and the journey time will be 120 min. This journey time does not include the waiting time and immigration process. The trains are expected to run at 300 km/h or faster; however, the average speed will be lower due to the slower speed to approach the stations.

The preliminary baseline alignment has been developed by SPAD as shown in Figure 1, but the detailed alignments remain confidential at this stage. The HSR will have a dedicated line, which is proposed to be a double track using a standard gauge. The HSR project is believed to impact the way of life for Malaysians and Singaporeans in terms of social, politics and economics. According to SPAD, the main objective of HSR is "to reduce travel time between Kuala Lumpur and Singapore to 90 min by strengthening the link between two of Southeast Asia's most vibrant and fast-growing economic engines compared to the 5 to 6 h journey time by road or over 6 h by conventional train" [4]. Although plane travel time is 90 min, similar to the proposed HSR, the hassle of long hours waiting before and after departures will actually give a total journey time of 4.0 h by plane [11]. In contrast, passengers can still board the HSR and even arrive at the railway station 15 min before departure. The CBD shown in Figure 2 is the Central Business District. The introduction of HSR will increase the daily journey from KL to Singapore and vice versa and at the same time, the quality of life of people in both countries will be improved, and the economics of both countries will grow considerably. The HSR, according to the International Union of Railways [12,13], has a lower impact on climate and environment than all other compatible transport modes such as aviation and road transport, which are highly dependent on fossil fuels. Adoption of HSR might provide a better solution with respect to reducing the climate impact.

Figure 1. Proposed High Speed Rail Malaysia to Singapore (courtesy: SPAD).

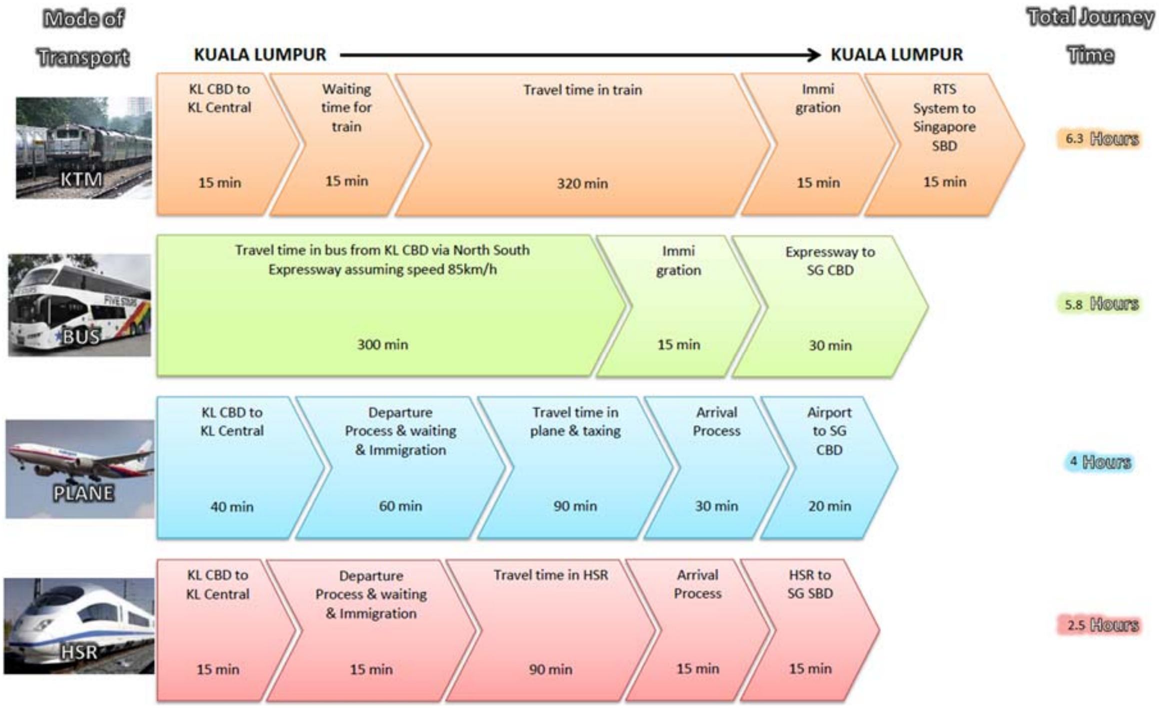

Figure 2. Travelling time from KL to Singapore: comparison between KTM, Bus, Plane and HSR (courtesy: SPAD).

Although the HSR has been proposed by both Malaysian and Singaporean Governments, the lack of progress can be observed and has given a window of opportunity to include the climate change risks and adaptation strategy in the detailed design stage of the HSR system. Despite considerable climate change research around the world, its application to risk assessment for high speed rails in Asia is not thoroughly investigated. This is because georisk hazards and their sensitivity to climate change cannot be adequately assessed at a high-level or top-down analysis. As a result, there is a need to assess climate change risk to high speed rail infrastructure at the design and construction stages. The main objective of this paper is to identify the risks imposed on the high speed rail system caused by local conditions including topographical, geological and climate change conditions of the proposed HSR route in Malaysia. The study also aims to evaluate how the infrastructure design can satisfy all the operational requirements given the climate impact issues. In carrying out this study, critical literature reviews were carried out. The data of Malaysia HSR are derived from SPAD, and the historical data of weather are supplied by the Malaysian Meteorological Department in order to study the impact of climate change and operational requirement for the design of the infrastructure. We aim to investigate the undefined risks due to climate change with respect to potential actions proposed to mitigate the impact. We have performed literature searches on open databases with respect to Malaysian local climate incidents and analyzed them. The insight will help engineers to better design and construct the infrastructure critical to economic growth of cities and regions. In this paper, the local priorities on climate change effects and the lessons pertaining to railway transport systems will be discussed first, and then geological and topographical issues and their association with the real climate change effects will be presented. Finally, the risk and consequences will be reviewed and analysed.

2. Climate, Geography and Lessons Learnt

Malaysia is divided into 2 parts, Peninsular Malaysia and East Malaysia (refer to Figure 3, which are separated by the South China Sea). Peninsular Malaysia is divided into 2 parts, west and east coasts, by the Titiwangsa Mountains. Figure 3 clearly shows that the South China Sea separates the climate change impacts in Malaysian geography, and the climate variation pertaining to the high speed rail line between Singapore and Malaysia is restrained by the shore surrounding the western peninsular.

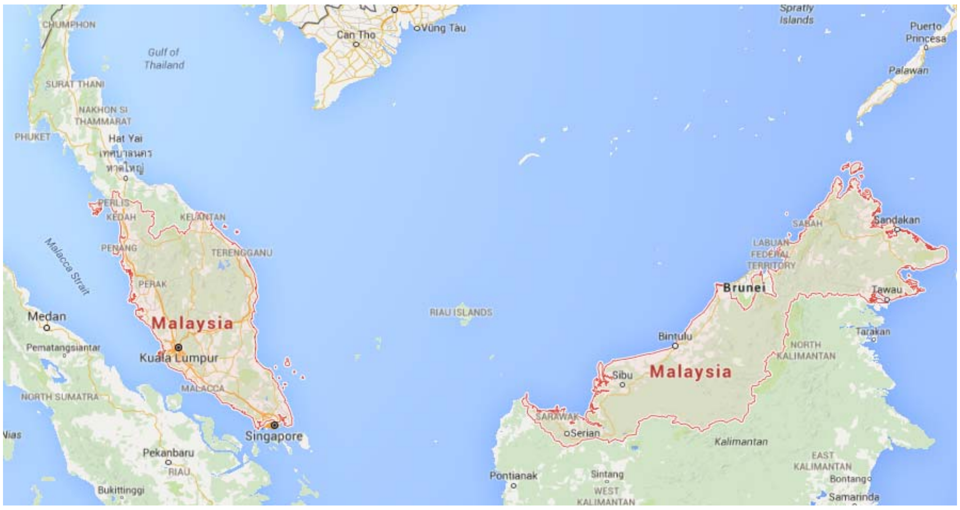

Figure 3. Malaysia Map from Google Maps.

The climate in Malaysia is dominated by 2 monsoon regimes, namely the northeast monsoon and southwest monsoon. The northeast monsoon circulates during the months of December, January and February, which is Malaysia's wettest season and the period where the most flooding occurs. Meanwhile, the southwest monsoon occurs between the months of May and September, the drier period for the whole country leading to droughts in this period. Being in the equatorial zone and a tropical country, the average temperature throughout the year is constantly high (26 °C) and there is very high humidity due to the high temperature. Malaysia also has very heavy rainfall which is more than 2500 mm per year [14].

"Warming of the climate system is unequivocal and since the 1950s, many of the observed changes are unprecedented over decades to millennia" [14,15]. According to the Malaysia Meteorological

Department [16], earth surface temperature records have clearly indicated that the climate of the earth is warming, with the rise being due to the increasing concentration of greenhouse gases (GHGs) in the atmosphere. Thus, in the next 50 years, Malaysia will experience higher temperatures, changing rainfall patterns, rising sea levels and more frequent extreme weather events ranging from drought to floods. The Malaysian famous rail jungle (east coast line) (refer to Figure 4), which is operated by National Malaysia Railway (KTM), was disrupted for almost 6 months due to the massive flood in December 2014. The damage included the railway quarters, signalling, tracks, locomotives, machinery and rolling stock. The disruption affected thousands of workers, traders and children going to school. There is still one stretch of line that is not back in operation due to the railway bridge in Kemubu, Kelantan, which completely collapsed as evidenced in Figure 5. Operation of the train service in the east coast is expected to be fully operational by February 2016 with the completion of the railway bridge in Kemubu. Construction of the new 250 m long bridge across the Nenggiri River is expected to cost RM30 million or GBP4 million [17]. This incident should provide a lesson to the railway industries and policy makers that extreme weather can have a severe impact to the transportation operations as well as their infrastructure [18–23]. Rebuilding railway infrastructure is not easy and very costly; thus, to provide a reliable railway system into the future, studies of the impact of climate change are needed [24]. From these studies, the adaptation of railway infrastructures and rolling stock to climate change could be established.

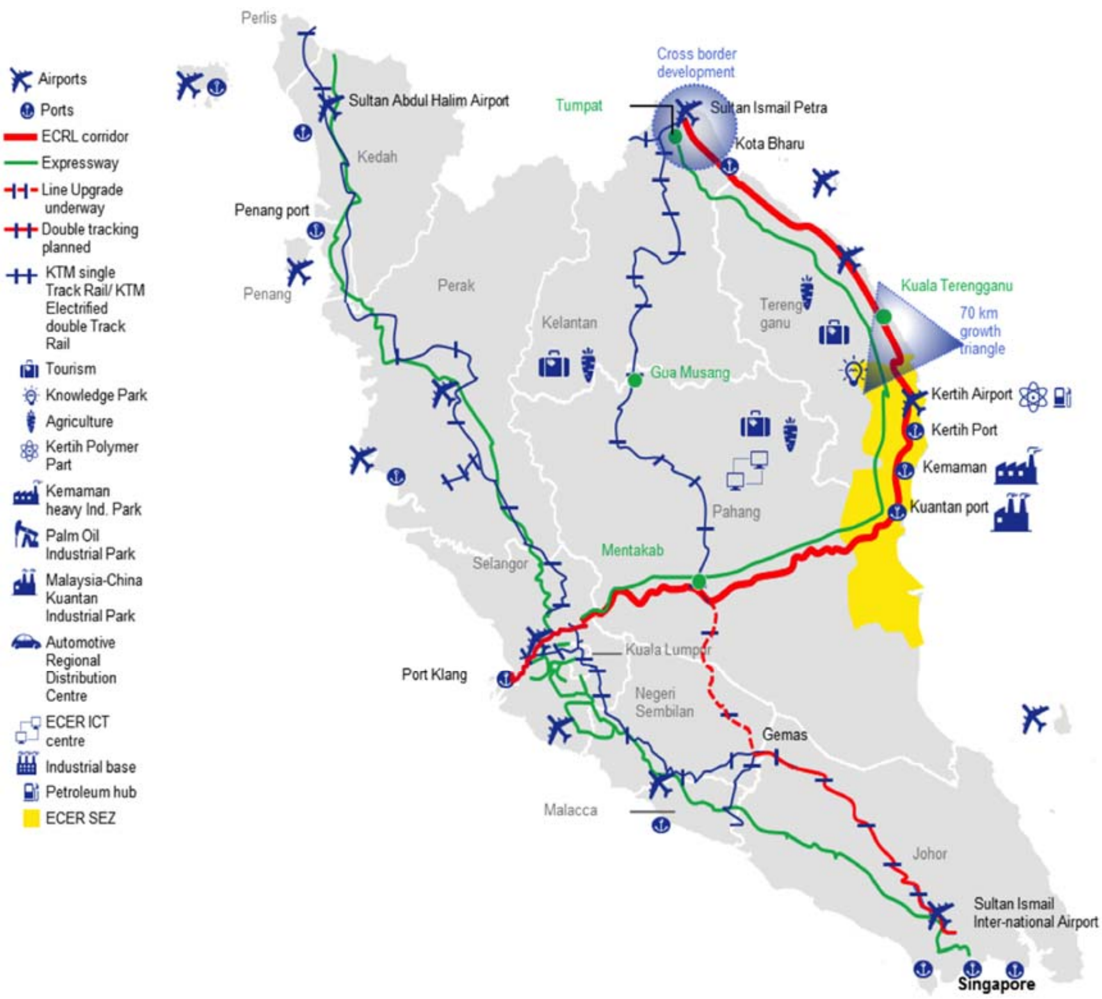

Figure 4. Malaysia rail map (courtesy: SPAD).

Figure 5. Malaysia East Coast Line railway bridge which crosses Nenggiri River in Kemubu, Kelantan was completely lost due to massive flooding in December 2014 (courtesy: Malaysia Department of Public Works).

3. Topographical and Geological Challenging Conditions to Malaysia

To thoroughly assess emerging risks, it is essential to understand conditions of the soils and potential foundation of rail infrastructure, which is highly sensitive to climate. It has been decided by SPAD that the HSR Malaysia route will be along the coastal area. Malaysia comprises a wide range of rock types from the sands and silts of the coastal plains to the granite of the Main Range. Geologists, as shown in Figures 6 and 7, grouped the rocks according to their type, age and environmental deposition. The most widely used unit for geology reference is based on the formation; each type is given its own geographical name. In Peninsular Malaysia, the geology range from Cambrian to the Quartenary, that is from 570 million years to about 10,000 years ago, is represented and shown in Figure 6. Sedimentation was unremitting throughout the Palaezoic and Mesozoic eras and due to the basin instability, there were major faults within and between the Palaezoic, Mesozoic and Cenozoic group of rocks, which are grouped according to four types of belts, namely the Western Belt, Bentong-Raub Suture, Central Belt and Easter Belt zone. Thus, Granitoids occupy nearly half of Peninsular Malaysia.

From Gunung Gagau in the north to Gunung Panti in the south, which is located at the eastern Peninsular of Malaysia, sedimentary basins can be found. The sediments, which comprise sandstone, conglomerate and shales with minor coal seams and volcanic, show fluvial, lalcustrine and deltaic conditions of deposition. Geological Maps of Peninsular Malaysia in Figure 6 show that Malaysia's coastal area consists of mostly quarternary deposits [25,26]. Only in the straits of Malacca is the coastal geology in the form of ordovicion phylites, schists and limestone. Kinta and Klang Valley contain valuable tin ore. Thus, Kuala Lumpur in Klang Valley was named the capital city of Malaysia due to the rise of tin mining in the middle of the 19th century.

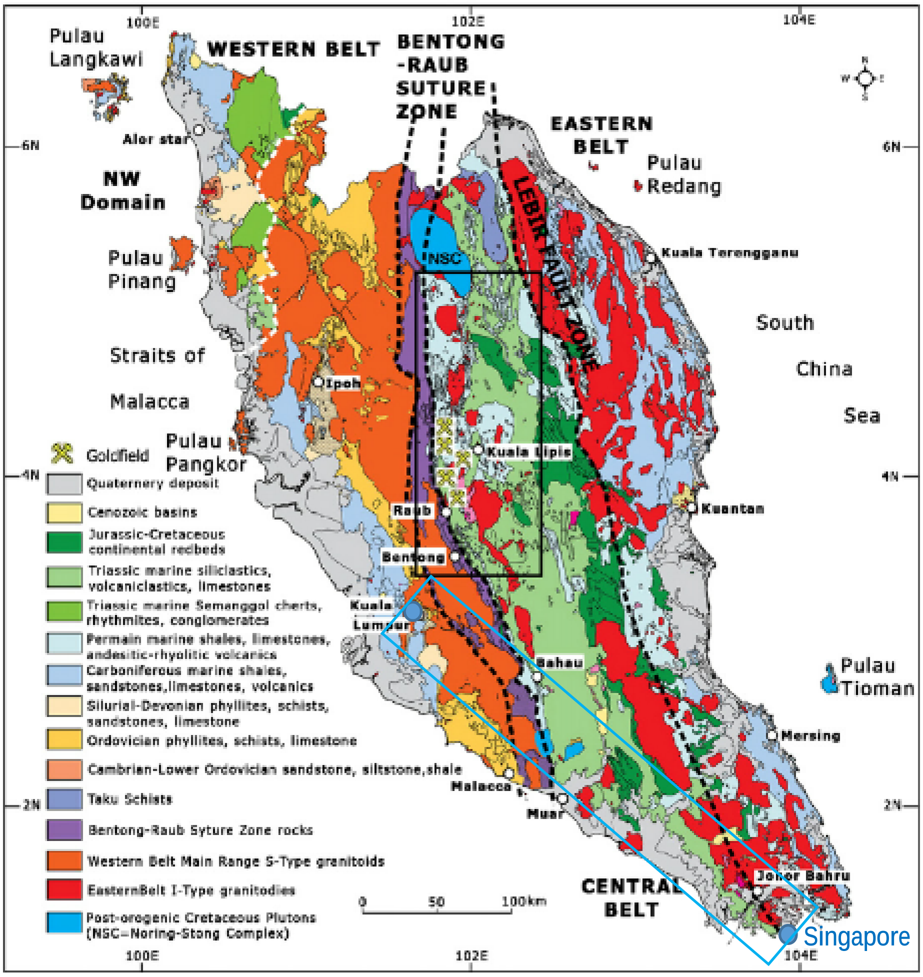

Figure 6. Geology Map of Peninsular Malaysia, modified from [25].

As shown in Figure 8, the proposed HSR route starting from Kuala Lumpur will pass through a carboniferous area, which prominently consists of limestone. The route then will cross granite in the Seremban area. Towards to the south, the alignment will pass through the limestone and sandstone area. In the south bound region, the HSR route from Melaka to Nusajaya lies on the coastal area matching the geology profile of marine and continental deposits. Mostly, the soil conditions are basically in the form of clay, silt and peat.

According to Bakshipouri et al. [27,28], approximately 40% (236.827 km^2) of the Kuala Lumpur area is underlain by unique limestone and karst, which are extensively developed and classified as extreme Karst class Kv (see Figure 7). The process of karst formation commences as rainfall (H_2O) that passes from the atmosphere onto the top, where it then infiltrates into the ground. Mixed with (CO_2) gas from the air and soil, this water produces a weak carbonic acid (H_2CO_3), which seeps further into the ground and makes contact with the limestone ($CaCO_3$) and/or dolomite ($CaMg(CO_3)_3$). Figure 8 shows typical morphological ground conditions within five classes of the engineering classification of karst. These examples show horizontal bedding of the limestone; dipping bedding planes and inclined fractures add complexity to most of the features and also create planar failures behind steep cliff faces. The dotted line represents any type of clastic soil or surface sediment [29].

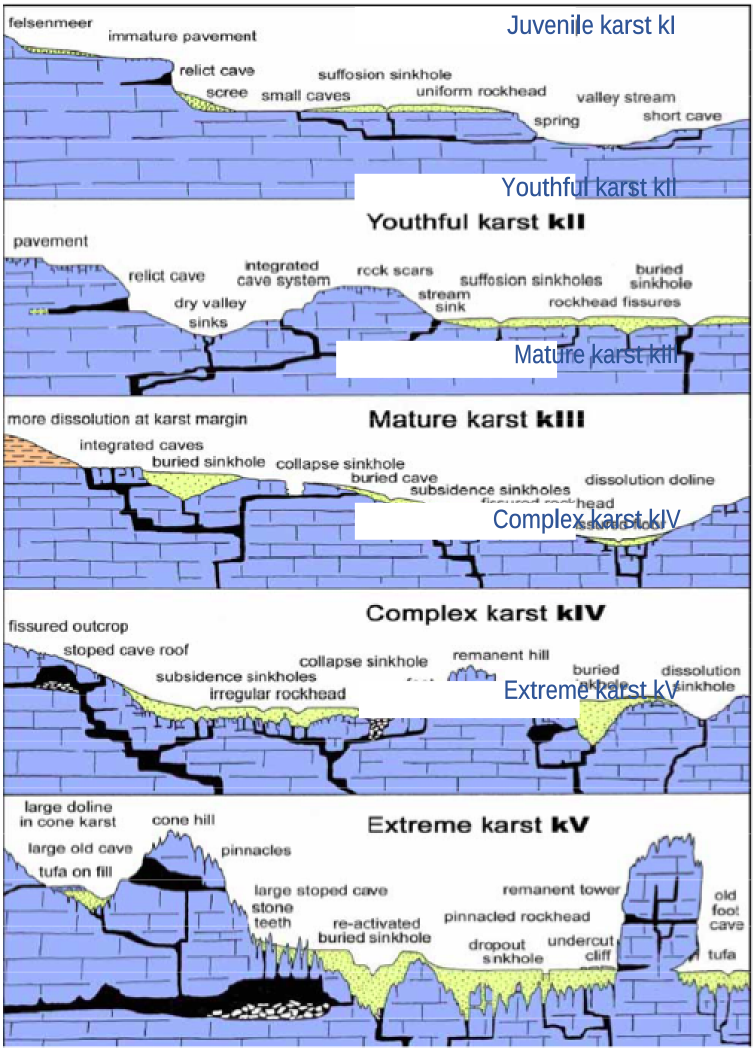

Figure 7. Typical morphological features of karstic ground conditions within five classes of the engineering classification of karst, modified from [29].

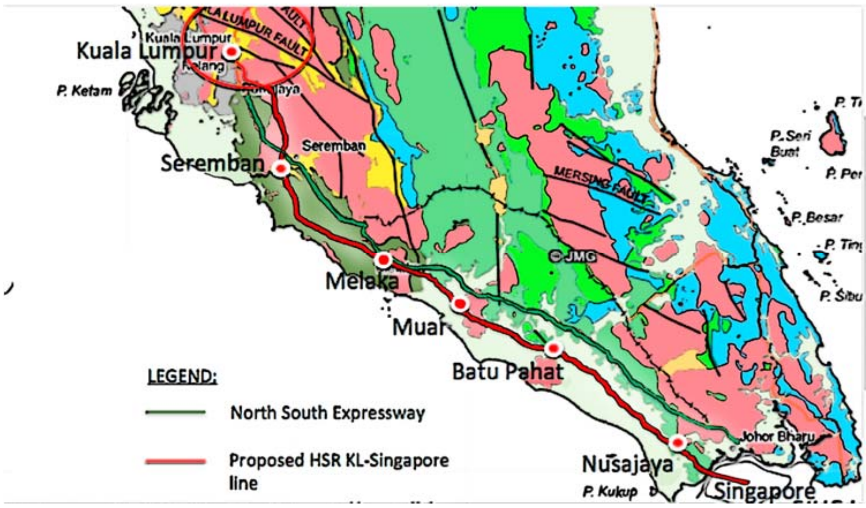

Figure 8. *Cont.*

QUARTENARY	Marine and continental deposits; clay, silt, sand, peat with minor gravel. Basal of Early Pleistocene age in Kuantan Area
TERTIARY	Isolated continental basin deposits of Late Tertiary age, shale sandstone, conglomerate and minor coal seams. Volcanics are in the Segamat area.
JURASSIC-CRETACEOUS	Continental deposits of thick, cross-bedded sandstone with subordinate conglomerate and shale/mudstone. Volcanics are locally present.
TRIASSIC	Interbedded sandstone, siltstone and shale; widespread volcanics, mainly tuffs of rhyolitic to dacitic composition in Central Peninsular. Limestone is prominent in lower part of the succession. Conglomerae and chert are locally prominent.
PERMIAN	Phyllite, slate and shale with subordinate sandstone and schist. Prominent development of limestone throughout the succession. Volcanics, mainly rhyolitic to andesitic in composition are widespread.
CARBONIFEROUS	Phyllite, slate, shale and sandstone; argillaceous rock are commonly carbonaceous. Locally prominent development of limestone. Volcanics of acid to intermediate composition are locally present.
DEVONIAN	Phyllite, schist and slate; limestone and sandstone are locally prominent. Some interbeds of conglomerate chert and rare volcanics.
ORDOVICIAN-SILURIAN	Schist, phyllite slate and limestone. Minor interlocations of sandstone and volcanics.
CAMBRIAN	Sandstone with subordinate siltstone, shale and minor conglomerate.
PERMIAN-JURASSIC	Intrusive rocks, mainly granite with minor granodiorite.

Figure 8. Geological Map of the HSR Malaysia route, modified from [25].

4. Global and Malaysia Climate Change Predictions

4.1. Climate and Weather

The American Meteorological Society defines climate as: "The slowly varying aspects of the atmosphere-hydrosphere-land surface system. It is typically characterised in terms of suitable averages of the climate system over periods of a month or more, taking into consideration the variability in time of these averaged quantities". According to Dessler [30], weather refers to the actual state of the atmosphere at a particular time. For example, weather in Birmingham on 26 July 2015 was sunny for the whole day without any precipitation with a temperature of 19 °C during the day and 10 °C at night. Climate, in contrast, is used as a statistical description of the weather over a period of time, usually a few decades. Climate is a record which indicates the low and high temperatures at certain places for a period of time.

4.2. Global Climate Change

The American Meteorological Society defines the term climate change as follows [31]: "It is any systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer". In other words, if there is any change between statistic of weather for such a period A and period B, that is climate change. According to the observations of the IPCC Working Group 1 Summary for Policy makers (SPM) of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report [31], the evidence for rapid climate change is compelling:

i. Global temperature rise
ii. Sea level rise
iii. Warming oceans
iv. Shrinking ice sheets
v. Declining Arctic sea ice
vi. Glacial retreat
vii. Extreme events
viii. Ocean acidification
ix. Decreased snow cover

4.2.1. Global Temperature Rise

One of the parameters often associated with climate change is temperature. Since 1850, in each of the last 3 decades, the Earth's surface has constantly experienced increasing warmer temperatures. The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere [32]. As shown in Figure 9 below, for the period 1880 to 2012, there was a linear warming trend of 0.85 (0.65 to 1.06) °C [2] for globally averaged combined and ocean surface temperature data. The different colours in the graph indicate different data sets. The ocean warming increased near the surface, and the upper 75 m warmed by 0.11 (0.09 to 0.13) °C per decade over the period 1971 to 2010.

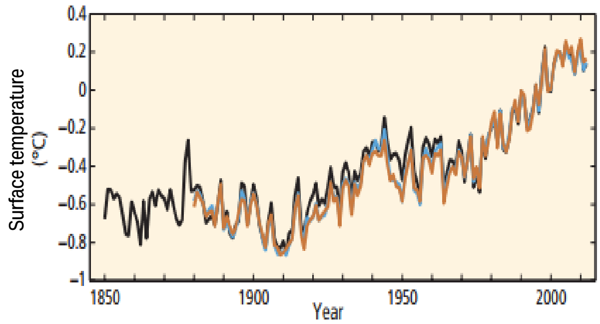

Figure 9. Globally averaged combined land and ocean surface temperature anomaly, modified from [29].

4.2.2. Sea Level Rise

Sea level rise can be related to climate change due to two reasons [30]: first as terrestrial ice melts, the melted water runs into the ocean, increasing the total amount of water in the ocean and therefore the sea level. Secondly, the water level expands when it warms. Figure 10 shows the global mean sea level increased by 0.19 m between 1901 and 2010. That is 1.7 mm/year in 1901 to 3.2 mm/year in 2010. Since the mid 19th Century, the rate of sea level rise has been greater than before. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading.

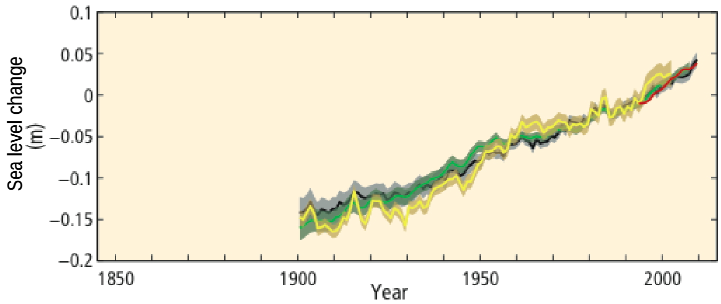

Figure 10. Global average sea level change, modified from [29].

4.2.3. Extreme Events

According to the IPCC [31], it is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale, and it is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. Precipitation has also increased rather than decreased. In North America and Europe, the frequency and intensity of heavy precipitation events are likely greater than before.

4.3. Malaysia Climate Change

Past Climate Trends

Malaysia is located near to the equator and is thus characterised as a tropical country with a monsoon climate, given the heavy and constant precipitation all year round. The weather is strongly influenced by the topographical features such as the mountain and sea land configuration. Two monsoons which dominate the Malaysia climate according to the Malaysia Metereological Department [16] are the summer Southwest Monsoon that influences the climate of the region from May to September, and the winter Northeast Monsoon from November to February. Tropical storms and depressions form in the South China Sea and the Indian Ocean sector.

The obvious change in climate that Southeast Asia is currently experiencing is increasing surface air temperature. The El Nino-Southern Oscillation (ENSO), time-scale-based oscillation of the Indian Ocean Dipole (IOD) and the intraseasonal Madden Julian Oscillation (MJO) may influence extensively the observed interannual and intraseasonal rainfall distribution in Southeast Asia. There are several studies that demonstrate tropical cyclones originating in the Pacific have increased, with a major impact on the Philippines and Vietnam, including the Peninsular Malaysia southern bound massive flood in 2006 and 2007 [33]. The increasing temperature and decreasing rainfall have both significantly increased the intensity and spread of forest fires in Southeast Asia. Fires in peat lands in Indonesia during the El Nino dry season are now common every year and cause haze in most ASEAN countries. The countries that are badly affected due to this haze are Indonesia, Malaysia and Singapore. In 2005, the Prime Minister of Malaysia declared a state of emergency in Port Klang, Selangor, 40 km from Kuala Lumpur after the Air Pollution Index reached 500—the emergency level [34].

(a) Temperature

The Malaysia Metereological Department [16] has selected Kuching, Kota Kinabalu, Kuantan and Petaling Jaya meteorological stations to represent West Malaysia and Peninsular Malaysia, respectively, to study the trend of both temperature and rainfall data over the last 40 years (1968–2007). Figure 11 shows increasing temperatures throughout the 40-year period for the four stations. Kuching shows the smallest increase in temperature, which may be due to the larger areas of forest cover in Sarawak and the least urbanisation compared to the other states in Malaysia. There was also evidence that strong El Nino events were recorded in 1972, 1982, 1987, 1991 and 1997 that are related to the significant rise in temperature recorded (Figure 12).

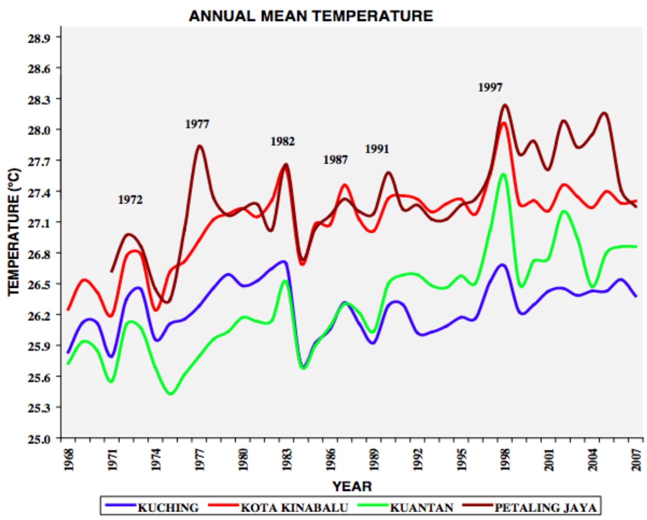

Figure 11. Annual Mean Temperature Trend for 4 Meteorological Stations (Courtesy: Malaysia Meteorological Department).

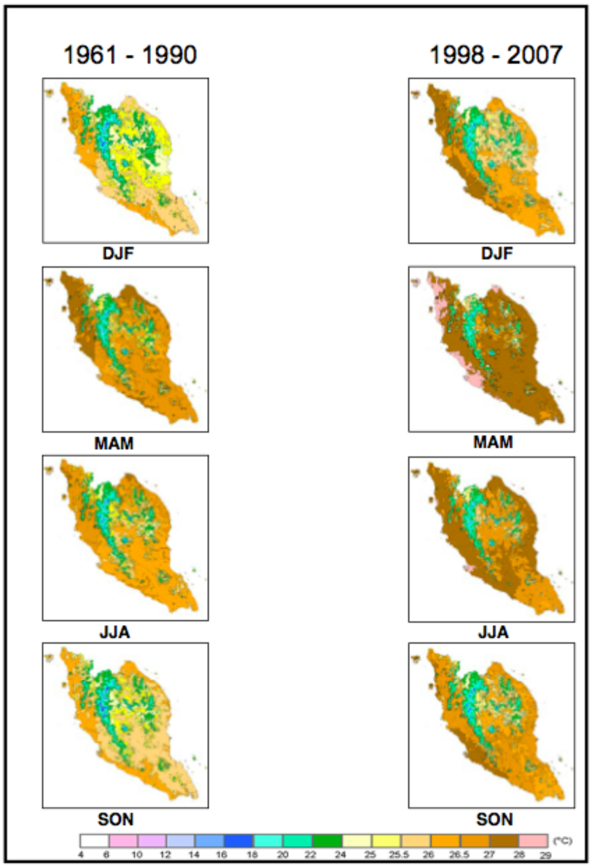

Figure 12. Long-Term Mean Temperature for West Malaysia. Colours indicate the temperature in degrees Celsius. DJF-December, January, February. MAM-March, April, May. JJA-June, July, August. SON-September, October, November (Courtesy: Malaysia Meteorological Department).

Seasonal mean temperature for Peninsular Malaysia is shown in Figure 12 and is categorised as 30-year (1961–1990) temperature and 10-year (1998–2007) temperature. The analysis performed by the Malaysia Metereological Department [16] is divided into 4 seasons, December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON). It is shown in Figure 12 that, despite a 10 or 30 year duration, MAM and JJM are the warmest and coldest seasons in Malaysia, respectively. Figure 12 also clearly shows that Malaysia is getting warmer. According to the Malaysia Metereological Department [16], an average temperature increase of 0.5 °C to 1.5 °C was recorded in Peninsular Malaysia and SON recorded the highest temperature increase followed by DJF.

(b) Rainfall analysis

Malaysian rainfall distribution patterns are determined by both seasonal wind flow patterns and local topographic features. The east coast of Peninsular Malaysia is likely to have more heavy rain as the area is more exposed to the South China Sea. However, the west coast area of Peninsular Malaysia is likely to be sheltered from heavy rains due to the topographical features. Thus, the east coast has experienced more flooding during the monsoon season compared to the west coast. Figure 13 shows the average occurrence of rainfall based on the south coast, high land, east coast and west coast of Peninsular Malaysia. Readings were recorded from 12 am till 9 pm. It is stated that the south coast will experience more rainfall during April, and the east coast will get more rainfall in the same month due to the seasonal times. Figure 14 shows the Long-Term Mean Rainfall for Peninsular Malaysia, the colours indicate the total rainfall in mm. DJF-December, January, February; MAM-March, April, May; JJA-June, July, August; SON-September, October, November [16]. Comparing actual records of rainfall quantity between 1961–1990 and 1998–2007, it is found that the Peninsular experienced more rainfall in the latter period, demonstrating the solid evidence of climate change.

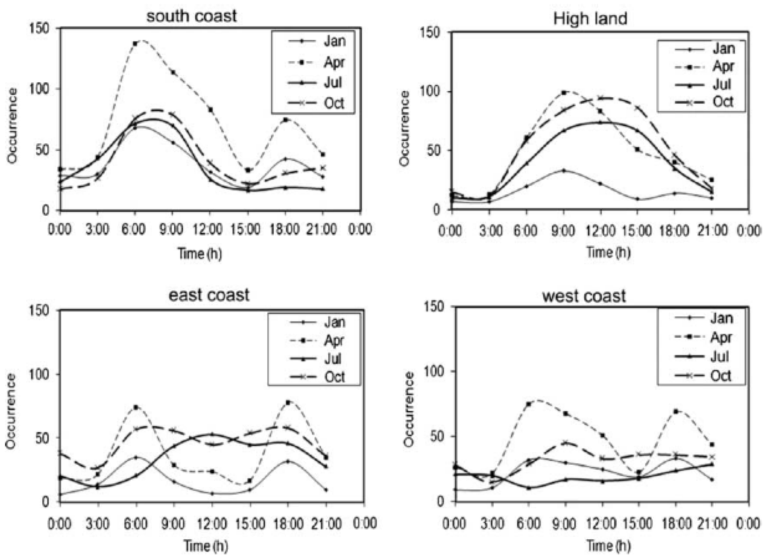

Figure 13. Occurrence of rainfall based on the south coast, high land, east coast and west coast of Peninsular Malaysia (Courtesy: Malaysia Meteorological Department).

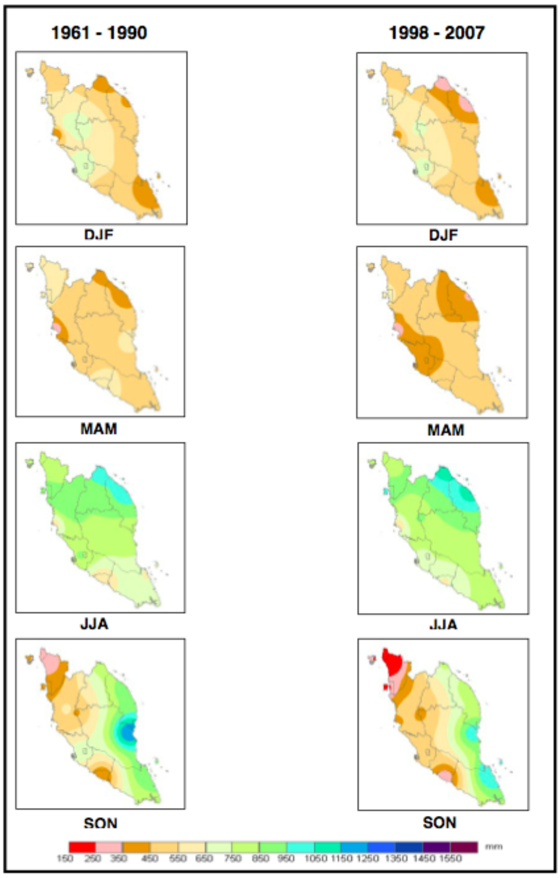

Figure 14. Long-Term Mean Rainfall for Peninsular Malaysia. Colours indicate the total rainfall in mm. DJF-December, January, February. MAM-March, April, May. JJA-June, July, August. SON-September, October, November (Courtesy: Malaysia Meteorological Department).

5. Climate Change Effects on Extreme Weather and Associated Effects on Railway Infrastructure

Extreme weather events have occurred frequently in Malaysia over the past decade. The most devastating natural disasters experienced in Malaysia are floods and landslides.

5.1. Floods

The destructive flood in southern peninsular of Malaysia, which occurred in two events back to back in December 2006 and January 2007, is known as Typhoon Utor. The massive flood in Kota Tinggi Johor started when the Northeast monsoon brought heavy rain through a series of storms. The series of floods were unusual as the 2006 average rainfall return period was 50 years, while 2007 had more than a 100-year return period. Local weather changes are among the natural causes that triggered the flash flood [35,36].

5.2. Landslides

Asia has suffered more landslides compared to other world regions due to its climate nature. According to United Nations University [37], among natural disasters, landslides are the seventh ranked killer, after windstorms, floods, droughts, earthquakes, volcanos and extreme temperatures, among which an average of 940 people annually were killed by landslides in the decade 1993 to 2002, most of those victims from Asia. There are many factors that can trigger landslides including changes in slope geometry, water level, rainfall intensity, and loading. However, the major cause of landslides in Malaysia is high precipitation.

As Figure 15 shows, traffic may slow due to rock falls but can still swerve and go around the debris; however, this is different with trains. The trains do not have this option even if the smallest landslide occurs on the railway line. This brings greater risk to the trains and its passengers. It is important for the infrastructure manager to design the slope and track embankment with the consideration of extreme rainfall due to climate change.

Figure 15. The Bukit Lanjan rockfall along the New Klang Valley Expressway in November 2003 resulted in a six-month closure of that particular stretch (Courtesy: Malaysia Department of Public Works).

The wettest winter on record in England and Wales caused widespread and severe consequences including flooding and disruption to road transport in the Somerset Levels. It also caused the collapse of the iconic South Devon Railway sea wall at Dawlish (refer to Figure 16), undermining rail access to and from the counties of Cornwall and Devon [38–42]. This can be evidence of a secondary effect on a railway line.

Figure 16. The main railway line to Cornwall and Devon was demolished at Dawlish by storms, which hit the UK in February 2014 (Courtesy: Network Rail).

A rise in the sea level will automatically affect the reading of the 100-year flood level, which the Malaysian design standard normally adopts when designing a platform level bridge. There are many consequences for railway infrastructure due to hot and dry weather and the obvious example is the risk of buckling. According to Network Rail, the definition of buckling is the extent of track deformation constituting a reportable buckle that would render the line unfit for the passage of trains at line speed and/or necessitates emergency remedial work to a running line under cover of either a temporary restriction of speed or closure of the line. Buckling is very treacherous as it could cause derailment of the train and end up in the disruption of railway operation services. Figure 17 shows a Singapore bound train that derailed on 26 January 2013 due to rail buckling [11]. The wagons landed on their sides and trapped the workers, injuring five passengers. The train service to the southern part of Malaysia was disrupted for several days due to the difficulties rescuers had reaching the remote area where the incident happened.

Figure 17. KTMB train derailed due to rail buckling and landed on its side, trapping the driver and injuring about five passengers just before Kempas, Johor station, southern part of Malaysia (Courtesy: Malaysia Department of Public Works).

In the United Kingdom, the Railway Safety and Standards Board (RSSB) with involvement of the Met Office has assessed the risk of heat on railway assets and railway operation. Similar work on road infrastructure has also been carried out by the Scottish Road Network. The findings included:

- An increase in the number of days required to monitor track buckling and an increase in the frequency of speed restriction as a result.
- Reduction in productivity of the workers caused by heat stress.
- Passengers experiencing more heat stress.

6. Responses to the Threat of Climate Change

Malaysia has conducted several studies on the climate change scenarios through the Malaysian Meteorological Department and Ministry of Science, Technology and Innovation and several universities. However, there were only a few studies on the threat of climate change with respect to infrastructure, particularly in the railway industry. Based on the expert interviews at KTMB and SPAD using face-to-face and e-mail communications, the risks and vulnerable assets can be identified for Malaysian railway networks.

Collaborative research conducted by universities in Malaysia was focused more on climate change impact than on agriculture. It is thus important to first understand and be able to identify emerging risks to rail infrastructure at the design and construction stage. The insight into the risks and potential impact will enable better management of construction, better choice of materials, better planning for crisis and post-crisis management, and so on. Expert interviews of almost 30 experienced track and environmental engineers in Malaysia (from various organisations e.g., SPAD, KTMB, Department of Public Works, etc.) have been conducted. Face-to-face meetings and e-mail interviews had been kindly supported by governmental engineers and local consultants. Priority, likelihood and potential consequences of natural hazard threats were discussed and gathered based on a systems thinking approach. Based on critical risk analysis, Table 1 portrays possible risks and the vulnerability of the high speed rail assets in Malaysia. The ranking was based on the analysis and expert interviews from the Malaysian Department of Transport using previous experiences, soil and geological conditions, historical data of geo hazards and responses, and the data from SPAD on the track alignment and track structures. It is found that intense rainfall could trigger a number of emerging risks. In addition, because the neutral rail temperature has been designed at a higher degree in Asia, the risk ranking for rail buckling is not as high.

Table 1. Risks and vulnerable assets of high speed rail infrastructure in Malaysia.

Climate Impact Group	Vulnerable Asset	Infrastructure Group	Ranking
Intense rainfall	Embankments	Geotechnical	1
	Rock cuttings		2
	Earth cuttings		3
	Drainage	Civil	4
	Culverts		5
Storms	Trains	Operation	6
	Signalling equipment	Signals	7
Flash flood	Trains	Operation	8
	Signalling equipment	Signals	9
	Embankments	Geotechnical	10
	Track circuits	Electrical	11

Table 1. *Cont.*

Climate Impact Group	Vulnerable Asset	Infrastructure Group	Ranking
Extreme heat	Signalling equipment Mechanical equipment	Signals	12 13
	Complex junction Overhead wire	Track Electrical	14 15
Bush fire	Electrification	Electrical	16
Intense rainfall	Trains Railway station	Operation	17 18
	Train function	Rolling stock	19
Extreme heat	Passenger comfort Train function	Operation Rolling stock	20 21
Intense rainfall	Complex junction	Track	22
Storms	Overhead Wiring Regulator Ballast washaway	Electrical Track	23 24
Sea level rise	Trains Stations/Platforms	Operation	25 26
	Tunnels Bridges and viaducts	Civil	27 28
Intense rainfall	Bridge scour	Civil	29
Extreme heat	Rail bunching and/or buckling on sharp curve or steep gradient	Track	30

The Climate Change Act 2008 is an Act of the Parliament of the United Kingdom, who implemented a process by which statutory authorities, such as Network Rail, are required to comply with formal reporting requirements with respect to climate change adaptation [43,44]. According to Lane and Dora [41], in order to undertake the required reporting process, it is firstly necessary to identify the key activities that are required to develop a reliable method for the prediction of climate change impact as shown in Table 2.

Table 2. Proposed planning process for climate change adaption for HSR Malaysia.

No.	Planning Component	Purpose
1	Critical weather events	Knowledge and understanding of impact on HSR Malaysia
2	Critical components of HSR Malaysia	Knowledge and understanding of structural, systems and elemental response and vulnerability to critical weather events
3	Prediction of climate change impact	Methodology for predicting the impact of specific critical weather events on components of the HSR Malaysia
4	Development of adaptation options	Permits evaluation of different adaptation policies that are practical, cost-efficient and suitable to localised issues
5	Design standards	Identification of changes to design standards to mitigate the impact of climate change
6	Management policy	Identification of changes to management policy to mitigate the impacts of climate change

In this case, Malaysia HSR could adopt this planning and perhaps this policy can provide guidance for the other rail operators such as KTM and Rapid KL [45]. The assessment of the risks and consequences of the critical weather events with respect to HSR Malaysia and possible adaptation measures are thus shown in Table 3.

Table 3. Risks and adaptation measures for high speed rail in Malaysia.

Climate Impact Group	Risks	Safety Impact	Performance Impact	Likely Negative Impact from Climate Change	Long or Short Term	Adaptation Measures
Sea Level Rise	Increased flooding generally	Medium	High	High	Long	Platform level need to cater to sea level rise and drainage design must cater to Average Recurrence Interval (ARI) plus climate change projection.
Increased Rainfall	Landslide	High	High	High	Long	Drainage design must cater to Average Recurrence Interval (ARI) plus climate change projection
Increased Rainfall	Settlement	High	High	Low	Long	Need to monitor the ground movement and the relation with rainfall intensity especially at the karst area in Kuala Lumpur.
Heat	Track buckling	High	High	High	Long	Need to study rail design resilience to high temperature or provide watchmen, condition monitoring and appropriate inspection strategies.

7. Conclusions

The global community recently agreed in COP2016 in Paris that climate change is real and unequivocal. However, Malaysia is still far behind in terms of assessing the risks of climate change, especially with respect to its existing railway systems. Our critical review has found that there was a lack of studies on the real effect of climate change with respect to the Malaysian railway operation and to the local railway infrastructures. In particular, the projected urban growth in Kuala Lumpur and Singapore has led to the necessity to establish improved transport links between the two cities, including road, aviation, ports and rail. Recently, a High Speed Rail (HSR) system has been jointly proposed by both the Malaysian and Singaporean Governments. However, the existing railway network in the region has been affected significantly by severe weather conditions such as rainfall, lightning, wind and very high temperatures. Now that Malaysia is planning to design and build the new HSR, mitigation and adaption measures pertaining to the risk of climate change are a must to ensure that we together can achieve and deliver:

- A safe railway
- A highly reliable railway
- Increased capacity
- Value for money
- Predictable and preventable ethos

The risk, safety and performance impact of each climate impact group on the operation of HSR Malaysia has thus been evaluated and highlighted in this paper. Based on critical risk analysis and expert interviews, the responses to the threat of climate change have been initially proposed for the Malaysia-Singapore HSR system. We found that the most critical risks involve intense rainfall, which undermines embankments, rock cuttings, earth cuttings, and drainage and culvert systems in the railway network. This is due to the fact that the geotechnical and geological conditions in the rail network are highly sensitive to moisture content and pore water pressure. The insight based on a critical review of open literature and evaluation of expert interviews from this study will help design engineers, constructors, maintainers and asset owners to plan and prepare for operational readiness of high speed rail networks under an uncertain climate. On this ground, planning and design of HSR are required in order to appropriately respond and adapt to climate change. By adopting adaptation measures, Malaysia can mitigate both performance and safety impacts related to climate change over the long term. The scope of this work is focused on risk profiling of high speed rail development. Future work includes resilience-based design and planning of the system associated with localized climate change potential.

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